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ON-LINE COLOIMETRIC ANALYZERS FOR MONITORING NITRATE-NITRITE, AMMONIA, ORTHOPHOSPHORUS AND TOTAL HYDROLYZABLE PHOSPHORUS IN WASTEWATER-TREATMENT PROCESS STREAMS

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Presented is a desktop survey of commercially available, on-line, colorimetric analyzers for monitoring nitrate/nitrite, ammonia, ortho-phosphorus and total hydrolyzable phosphorus in wastewater-treatment process streams. Also furnished is an example estimate of capital and operating costs for a continuous on-line ammonia analyzer, including a remotely located, controlled-environment, auxiliary instrument building.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This survey of commercially available, on-line instrumentation for monitoring and control of wastewater treatment is intended to guide those in the field in selecting up-to-date equipment that is tailored to their particular needs and that will produce fast, precise, accurate measurements at the most reasonable cost possible.

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ON-LINE COLORIMETRIC ANALYZERS FOR MONITORING NITRATE-NITRITE, AMMONIA, ORTHOPHOSPHORUS AND TOTAL HYDROLYZABLE PHOSPHORUS IN WASTEWATER-TREATMENT PROCESS STREAMS

INTRODUCTION

The following survey of commercially available instrumentation for on-line monitoring or control of the subject process parameters is intended to be thorough, but not exhaustive. Analyzers that were developed for use in laboratory environments and that are too delicate and fragile for in-plant wastewater-treatment monitoring and control situations are not included in this report. Also not included are analyzers still under development, as well as those that have not yet been sufficiently field tested to establish their on-line reliability or their performance characteristics. This has resulted in the exclusion of Technicon's AutoAnalyzer and CSM-6, and Raytheon's colorimetric WetChemAnalyzer system for all parameters except orthophosphorus. Also excluded are Orion's Model 1100 ammonia monitor, EIl's Model 8002 ammonia analyzer, and Enviro Control's nitrate and ammonia analyzers, all of which employ ion-selective electrodes. The future developmental status and field performance results for these and new process analyzers will be closely followed.

On the other hand, Technicon's Monitor IV colorimetric analyzer has been included because it was specifically designed for rugged in-plant service, yet it can also determine any one of the subject parameters.

INFORMATION SOURCES

The following instrument manufacturers or developers were requested to furnish information for this survey*:

1. Technicon Industrial Systems, Tarrytown, N. Y.
2. Delta Scientific Corporation, Lindenhurst, N. Y.
3. Raytheon Company, Environmental Systems Center, Portsmouth, R. I.

*Current catalogs of Honeywell, Inc., Leeds & Northrup Company, The Foxboro Company, and Fischer & Porter Company gave no listings of on-line colorimetric analyzers for any process parameter.

4. Enviro Control, Inc., Rockville, Md.
5. Ionics, Inc., Watertown, Mass.
6. Dow Chemical Company, Midland, Mich.
7. Beckman Instruments, Inc., Process Instruments Division, Fullerton, Calif.
8. duPont's Instrument Products Division, Wilmington, Del.
9. Union Carbide Corporation, Bound Brook, N. J.

Of these nine candidates, only the first five presently market on-line wastewater analyzers for the subject parameters. Dow Chemical invented and used an automatic orthophosphate analyzer for their own in-house needs, but it was subsequently licensed to Ionics for further development and sale to the general public.

The following items at least warrant mention to alert the reader to new concepts and equipment now under development:

a) Beckman Instruments, Inc., indicates that they have reduced to practice a revolutionary new analytical concept for determining all of the subject parameters except phosphorus. This new Beckman analytical system requires only a single, general-purpose "analyzer section" to which can be attached any combination of four modular subsystems for determining total-N, NH_3-N, NO_3/NO_2-N, and cyanide N. Beckman is aiming for production models within 1 to 1½ years, and they are convinced that their novel device will be technically superior to present nitrogen analyzer systems. Cost advantages, however, are anticipated only for those applications requiring measurements of at least two or three of the four forms of nitrogen just described

   Less sophisticated on-line instrumentation for NO_3-NO_2 and orthophosphorus should be commercially available from Beckman in 6 to 8 months.

b) Union Carbide has stated that they have programs underway to develop total N and P devices. The total N device employs an improved Orion NH_3 electrode as its sensor. However, the analytical principle upon which the total P device is based was not disclosed.

PRESENTLY AVAILABLE EQUIPMENT

Technicon's Monitor IV System

These colorimetric instruments are essentially steel-encased, compact, on-line versions of Technicon's AutoAnalyzer II counterparts. They weigh about 140 lb (63.5 kg) and are approximately cubical in outer configuration (22½ x 24 3/4 x 18½ in.; 57 x 60 x 47 cm). However, any addition of optional accessories necessarily increases the overall weight and external dimensions of the Monitor IV system. Each instrument is capable of measuring only one of the subject parameters at a time; by a change of reagents and certain internal components, however, this analyzer can be modified to measure any one of a wide variety of process parameters (see Table 1). Each analyzer is designed to operate, relatively unattended, for extended periods of time in "process" or "plant" environments--not, however, in open areas or with any direct exposure to weather.

The Monitor IV employs basic AutoAnalyzer II hardware for its operating components: a two-speed peristaltic proportioning pump, analytical manifolds to control the flows of sample and reagents (and to program the analytical reaction sequence), time-delay coils, heating baths, a dual-cell linear-output colorimeter, a stripchart recorder, and programmed automatic recalibration that can be used, alternatively, to correct the system for baseline drift.

The Monitor IV does not include a solids-removal filter as a standard component, but it can be externally fitted with either a continuous paper filter or a more expensive continuous filter/sampler. EPA Pilot Plant experience[1] with both of these Technicon sample-filtration systems indicates that the continuous filter/sampler is subject to more maintenance problems and requires much more expensive filter media than does the less-costly continuous paper filter.

In its present form, the Monitor IV cannot be fitted, even externally, with either an AutoAnalyzer distillation unit or Technicon's high-temperature helical digestor. However, this does not interfere with the instrument's ability to determine any of the subject parameters, especially since the development of a total hydrolyzable phosphorus method requiring sample hydrolysis at only 90°C.[2]

The reagent reservoirs are encased within the main Monitor IV cabinet. For most applications, this automatically increases routine maintenance costs. These encased reagent reservoirs necessarily are quite small (1-liter capacity) to conserve on

Table 1

MONITOR IV PARAMETERS[a]

Parameter	I.F. Wavelength
Ammonia	630 nm
Ammonia (Seawater)	630 nm
Nitrate & Nitrite	550 nm
Nitrate & Nitrite (Seawater)	550 nm
Nitrite	550 nm
Nitrite (Seawater)	550 nm
Ortho-Phosphate	660 nm
Ortho-Phosphate (Seawater)	660 nm
Total Inorganic Phosphate[b]	660 nm
Silicates	660 nm
Silicates (Seawater)	660 nm
Sulfide (Seawater)	660 nm
Total Iron (Soluble)[b]	660 nm
Hexavalent Chromium	550 nm
Copper	480 nm
Sucrose	480 nm

a. Analysis of additional parameters may be automated using the Monitor IV for specific requirements.

b. Requires second heating bath @ $426.00.

cabinet space, and normally they will supply the system for only 1 or 2 days. Technicon claims that operation of the pumping system at one-fourth normal speed will prolong the use of a given set of reagents by a factor of four. Unfortunately, this practice also increases the time per analysis by a factor of four (e.g., from 15 min to 1 hr). Most process-monitoring applications can tolerate this increased delay between analyses, but many process-control applications cannot.

An advantage of using the slower pumping rate is a prolongation of the usable lifetime of the analyzer's peristaltic pump tubing, again by a factor of about four (i.e., from 1-2 weeks, up to about 6-8 weeks) for those tubes that do not transmit highly corrosive reagents. Use of more expensive (but more durable) silicone-rubber pump tubing, rather than Technicon's standard Tygon pump tubing, should permit use of the faster (standard) pumping rate and yet minimize the frequency of pump-tube replacement. Unfortunately, reliable comparisons of the cost advantages of using silicone-rubber versus Tygon pump tubing are almost impossible to estimate because such information can only be determined experimentally for each particular analytical application.

Installation of a Monitor IV requires an isolated, grounded, stabilized, 110 to 120 V ac, single phase, 60 Hz power source that can furnish 5 amps. Installation also requires protective housing to exclude dust, dirt, corrosive fumes, and excessive moisture. This housing must be heated in winter and air conditioned during the summer because the Monitor IV is designed to operate satisfactorily only within the range of 50° to 90°F; humidity control is also desirable to protect sensitive electronic components. Special instrument buildings that meet these requirements are commercially available.[3] Obviously, it would be advantageous to place such analyzers in existing shelters whenever possible to avoid the additional cost and maintenance requirements for such individual weatherproof instrument buildings. Monitor IV installations must also possess drain lines or waste reservoirs to permit disposal of excess sample and "consumed" sample and reagents.

Technicon furnished no figures on the installation costs for their Monitor IV; they claim that the possible range of such costs is too broad for any estimate to be typical. On the other hand, Technicon was helpful in estimating equipment costs. Table 2 is a price quotation for the basic Monitor IV, plus available accessories and options. The basic unit costs $6,827; however, this price does not include a filter. If the basic analyzer is equipped with the cheaper of the two filtration units ($1,230) and a hi-level alarm with contact closure ($231), total equipment cost becomes $8,288.

Table 2

Cost of Basic Monitor IV Unit and Available Accessories

Basic Monitor IV:	
One integral monitoring unit incorporating a phototube colorimeter to provide linear readout and a 0-5 V dc signal, proportional to concentration, for data handling or storage, a two-speed proportioning pump, proportionally controlled adjustable heating bath, programmer mechanism for automatic recalibration against baseline or a known standard concentration, plattered manifold, one set of interference filters, 7 in. strip chart recorder, reagent containers and all necessary accessories.	$6,827.00
Continuous paper filter	1,230.00
Hi-level alarm with contact closure	231.00
Total Cost	$8,288.00

As standard equipment, the Monitor IV furnishes dual linear outputs: a 0-60 mv signal for use with a recorder, and a 0-5 V dc signal (proportional to concentration) for control functions, data handling and data storage.

Included with the purchase of each Monitor IV is thorough training in the use and maintenance of the analyzer at Technicon's central research facilities in Tarrytown, NY.

Biological fouling within the analyzer proper probably would not be excessive. However, biological growths in the analyzer's upstream sample feed lines could cause maintenance problems unless special preventive cleaning schedules were followed. Such schedules would have to be experimentally determined for each analyzer application, but the techniques employed would probably involve line flushing with some combination of mineral acid, hypochlorite, and water.

Delta Scientific's Series 8000 Continuous Automatic Analyzer/ Controller

This versatile, on-line instrument is a steel-encased, colorimetric analyzer/controller module that is quite similar to Technicon's Monitor IV in size and external configuration; however, it weighs only 80 lb (33.6 kg). The complete Series 8000 system offers a variety of electronically compatible accessory modules to expand the on-line capabilities of the main colorimetric Wet Chemistry Analyzer/Controller. For example, one or more remotely installed analyzer/controllers can be supplemented with a variety of extra readout units. These may consist of

-- an on-site recorder/digital readout module, dedicated to a single analyzer/controller,

-- a centrally located meter-readout module, serving several remotely installed analyzer/controllers, and

-- a centrally located recorder and/or digital readout module, also serving several remotely installed analyzer/controllers.

Of primary interest to this report, however, is the basic Wet Chemistry Analyzer/Controller. Like all items in Delta's Series 8000 line, their Wet Chemistry Analyzer/Controller was engineered from the time of conception to be used solely for on-line process monitoring and control applications. This does not mean, however, that any of Delta's Series 8000 equipment can be installed in-plant without the same type of protective environmental housing (including temperature and humidity control),

supporting utilities, drain lines, etc., that are required for installation of the Monitor IV. No existing "process" colorimeter can continue to function, much less furnish reliable analytical data, unless it is furnished with most of the protective and supporting facilities already specified above for the Monitor IV.

Delta's colorimetric analyzer/controller also can measure only one of the subject parameters at any one time. Therefore, to assure optimum accuracy and precision, the meter readout for each analyzer/controller is custom-made and factory-calibrated for a given parameter. Also, since the instrument employs separate optical cells for sample and reference streams, accuracy is enhanced by internally plumbing the system so that the total flow time through the analyzer (from initial splitting of the incoming process stream, up to the time each portion is finally measured in its separate optical cell) is exactly the same for both portions of the split stream. This, in turn, requires an internal flow delay for the reference stream, the duration of which is governed by the time required to develop the desired color for the sample stream. Since the speed of color development varies with the type of parameter being measured, the internal flow delay for the reference stream must also vary accordingly if both parts of the split stream are to be measured simultaneously.

Each Delta Wet Chemistry Analyzer/Controller embodies the following components: a patented, multi-section impulse pump (which actually serves as a pump manifold) for metering reagents and both portions of the split-process stream, a time-delay section, heating and sample-conditioning units to promote color formation, a dual-cell, linear-output colorimeter, and a meter readout with two adjustable pointers for setting hi-lo alarm limits. Recorders and digital readout units are optional accessories.

The analyzer/controller's split, incoming sample stream, plus the instrument's dual-cell colorimeter section, compensates not only for moderate sample turbidity, but also for known sample-color interferences. This latter is accomplished by insertion of appropriate optical filters in each of the two light paths. The power supply of the single, split-beam light source is stabilized against line-voltage fluctuations, and heat absorbing filters shield the optical cells from the lamp's heat. Both optical cell depths are individually selected to furnish optimum light-path lengths for the parameter and concentration range of interest.

Delta's pumping and metering system is designed to draw reagents directly from the bottles in which they are shipped. This does not mean that a user cannot prepare and standardize his

own reagents if he so chooses. However, Delta offers all reagents in stable, ready-to-use form for those who prefer not to prepare and standardize their own.

Like the Monitor IV, Delta's Series 8000 does not include a solids-removal filter as a standard component, but the analyzer/controller can be externally fitted with one. This optional accessory is called the Sample-Preconditioning Module, and it consists of a two-stage filtration system embodying a Cuno self-cleaning, edge-type roughing filter, followed by a proprietary self-cleaning, biocide-impregnated filter (20-μ pore size) that sterilizes the sample. For most wastewater-treatment applications, use of the Sample Preconditioning Module is mandatory, both to minimize internal fouling of analyzer components and to optimize the reliability of the analytical results.

Another optional accessory that greatly enhances the analyzer/controller's ability to handle samples of broad concentration ranges is Delta's automatic dilution apparatus. This embodies an ion-exchange unit (to demineralize the water used for sample dilution), plus an adjustable ratio-diluter.

As with the Monitor IV, reagent reservoirs are encased within the analyzer/controller's cabinet. Each of these four reservoirs holds 1 gal. of reagent; typically, this permits 8 to 10 days of continuous operation between refills.

The time lag between sample intake and analytical readout (i.e., signal output) ranges from 5 min for ammonia-N to 10 min for NO_3/NO_2-N. These are the response times required to reach maximum signal output--not merely the 90 percent of full-scale response time that many instrument manufacturers quote. It should be noted that the above range of 5 to 10 min for signal output may not apply to measurements of total hydrolyzable phosphorus. Delta only recently became aware of the new procedure for this latter parameter; therefore, the Wet Chemistry Analyzer/Controller's exact response time for total hydrolyzable P has not been established.

Delta's patented impulse pump does not employ the usual peristaltic rollers. This feature enables Delta to furnish a written guarantee that their pump tubing will not require replacement for at least 2 years unless the tubing is exposed to corrosive chemicals or to organic solvents that attack the tubing.

The Wet Chemistry Analyzer/Controller's power requirements are 250 W at 110 V, 60 Hz; or (optionally) 250 W at 220V, 50 Hz. Delta recently quoted an installed cost of approximately $5,500 for an on-line ammonia analyzer that would cover an NH_3-N

range of 0 to 40 mg per liter. In addition to the analyzer/controller, this cost also includes an automatic sample-preconditioning module, an automatic dilution apparatus, and training of the customer's equipment operator at Delta Scientific's laboratory. The $5,500 does not include any special protective (i.e., environmental) housing or the installation of supporting utilities and drain lines. Also, the quoted price includes no equipment (e.g., acid-metering pumps or water-flushing devices) to reduce upstream fouling of analyzer feed lines.

According to Delta Scientific, approximately the same price would apply to similar equipment packages for on-line monitoring and control of any of the other subject process parameters.[4] As standard equipment, each package would include automatically actuated, double-point, double-throw, 10-amp relays, plus hi-low alarm lights and proportional signal outputs in either mv, ma, or V dc. Audible alarms could be added for another $25 to $50.

Raytheon Company's Model 2512 WetChemAnalyzer for Orthophosphorus

This on-line colorimetric analyzer is also steel-encased, compact, approximately cubical in outer configuration (22 x 16 x 20 in.; 56 x 41 x 51 cm) and weighs only 80 lb (36.3 kg). Its reagent reservoirs are not located within the analyzer proper. A separate reagent-container housing is included as a standard accessory, however, and is sized to serve as an interlocking base, on top of which sits the main analyzer. Addition of the largest available reagent cabinet expands the system's configuration to 22 x 32 x 20 in. (56 x 81 x 51 cm) and increases the overall weight by at least 40 to 70 lb, depending on the size and number of reagent reservoirs employed. Addition of an optional sample-filtration system is mandatory for most domestic wastewater streams, and this further increases the overall weight and dimensions of the system by amounts that vary with the filtration unit selected.

Like Delta Scientific's Series 8000 analyzers, Raytheon's WetChemAnalyzers were engineered, from time of conception, to be on-line process monitoring and control devices. Another similarity is that each Raytheon analyzer can measure only one parameter at a time and cannot be readily converted to measure parameters other than the one for which it was initially constructed. Currently, Series 2500 WetChemAnalyzers are available for measuring orthophosphorus, copper, iron, hardness, alkalinity, hexavalent chromium, and total chromium. However, Raytheon has stated that similar analyzers for nitrate-nitrite, ammonia, and total hydrolyzable phosphorus (via Kamphake's new phosphorus method[2]) could be constructed if there were sufficient demand.

Each WetChemAnalyzer contains the following components: a multivane peristaltic pump for metering of reagent(s) and both portions of the split process stream (as with the Delta system, part of the stream is used as reference), a mixing and time-delay section, one or more sample-heating units, a dual-cell, linear-output colorimeter, meter-readout of analytical results, and 0 to 5 V dc and 0 to 50 mv dc linear outputs for driving recorders or remote indicators. All electronic components are solid state. Available at additional cost are recorders, voltage-to-current output converters (1-5 ma, 4-20 ma, and 10-50 ma), 10-amp hi-lo limit detectors (with contact closures), and sample filtration units.

As previously mentioned, the process stream is split into two parts almost as soon as it enters the analyzer. One portion of the split stream is mixed with the color-forming reagent(s); the other portion is time-delayed by long flow-coils. This eventually permits the simultaneous measurement of both parts of the split stream in separate optical cells to compensate for moderate turbidity and/or color initially present in the sample.

At extra cost, Raytheon can furnish either a simple wash-flow (i.e., self-cleaning) filtration unit or a complex dual-primary/dual-secondary automatic-switchover filtration unit, complete with automatic alarm, which signals that one of the two sets of primary/secondary filters needs replacing. The simple wash-flow unit costs about $200; the more complex, automatic, dual-filter system (Raytheon's Model 2550 Pretreat Unit) costs about $2,500.

Each of the WetChemAnalyzer's reagent reservoirs ordinarily holds a minimum of 1 week's supply of up to four reagents. However, if the largest available reagent cabinet is used, reagent supply may last longer than 2 weeks, depending on the parameter being measured. In any event, calibration should be checked on a weekly basis, as well as when reagent supplies are replenished. Calibration is simplified by built-in stream-selection valves so that an operator has only to manipulate external controls to calibrate the analyzer against two standard solutions of different concentrations.

Raytheon claims that analysis time for any parameter is less than 10 min from introduction of the sample to the WetChem-Analyzer. The analysis time for measurements of total hydrolyzable phosphorus using Kamphake's new method[2] has not been determined by Raytheon. Instrument-response time for each individual parameter is not typically furnished by most companies; however, it usually can be readily obtained upon request. Since the maximum response time for Delta's Series 8000 is also 10 min from sample introduction, and since both manufacturers probably use the same well-established colorimetric methods,

Raytheon's response times for individual parameters should be about the same as those quoted by Delta.

Raytheon quotes a peristaltic-pump-tube life of at least 1,000 hours (6 weeks) because their WetChemAnalyzer employs a unique low-speed pumping concept. This pumping system is also equipped with an audible over-pressure alarm to alert the operator of system plugging, and an audible under-pressure alarm to signal the occurrence of pump-tube rupture.

Installation requirements for a WetChemAnalyzer are the same as those for a Monitor IV. If the sample-filtration system employed were Raytheon's Model 2550 Pretreat Unit, internal biological fouling of the analyzer should not be excessive; however, biological fouling of the analyzer's upstream sample feed lines probably would present the same maintenance problems as could be expected with both the Monitor IV and Delta's Series 8000 analyzers.

The basic WetChemAnalyzer can be furnished to cover either of two ranges of orthophosphorus (i.e., 0-10 mg per liter, or 0-50 mg per liter) for $6,105. This price includes a reagent cabinet, but it does not include a recorder (these range from $400 for a single-point recorder to $2,150 for a multipoint recorder), E/I output converters ($150 each), a hi-lo limit switch ($200), or a sample-filtration unit (either $200 or $2,500, as previously described). The $6,105 also includes complete operator training at Raytheon's Portsmouth (RI) facilities in the use and calibration of the instrument system.

Enviro Control's Series 2000 Wet Chemical Analyzers

Only two models in this series are applicable to the subject parameters: one is the Model 2072 for measuring orthophosphorus, and the other is the Model 2080 for total soluble acid hydrolyzable phosphate. Both of these phosphorus analyzers are relatively new, and reliable users' experience is not yet available for either instrument.[5]

Each model in the Series 2000 is a compact, steel-encased, on-line, colorimetric analyzer that is rectangular in outer dimensions (48 in. wide x 24 in. high x 8 in. deep; 122 x 61 x 20 cm) and weighs about 125 lb (56.7 kg). The unit possesses a design configuration that allows ready access to

(1) The electronics assembly, all of which is attached to (and therefore swings out on) one of two hinged front doors;

(2) The wet chemistry section, mounted just behind the second hinged front door; and

(3) The reagent-reservoir compartment, which is located behind the swing-out electronics assembly.

All three of the above are thus completely exposed for maintenance by merely opening the front doors. The sample-filtration unit, which is mandatory for wastewater streams, is an external accessory that possesses its own housing.

The wet-chemistry section of both analyzers includes a low-cost and low-maintenance peristaltic-pump manifold (supplied by the Manostat Corp.) for metering reagents and both portions of the split process stream, a time-delay section, a unique mixing chamber with magnetic stirrer for rapidly mixing reagents and sample (this chamber reduces internal plumbing requirements and also almost halves the response time obtained with traditional mixing coils), a dual-cell linear-readout colorimeter, and both a meter and a stripchart recorder. In addition to these components, the Model 2080 requires a high-temperature (90°C) heating unit, as well as other supplementary hardware and electronics, to furnish automatic determinations of total soluble hydrolyzable phosphorus.

Two independently housed filtration units are available at extra cost: the Model 2050 single-stage filtration assembly ($1,850) and the Model 2052 dual-stage assembly ($2,250). For wastewater samples, Enviro Control recommends only the Model 2052, which is a continuous filter comprised of two stages in series. The first stage removes particles larger than 15 μm. The second stage further removes all particles larger than 0.45 μm. Each of the two stages contains two filters in parallel. In the first stage, both filters are of the self-cleaning type: when one of these filters eventually clogs, an alarm sounds and flow is automatically switched to the second filter so that the first can be cleaned without system shutdown. The second stage also has two filters in parallel, both of which are disposable. When the first filter becomes clogged, the same automatic alarm and flow-switching pattern occurs as for the first-stage filters. Replacement of the disposable filter-cartridge requires about 2 min.

An optional Model 1032 Alarm Module is also available for $150. This consists of hi-lo alarm lights and contact-closure relays with individually adjustable setpoints. These contact closures can be used for actuating remote process-control devices such as valves and pumps. The complete Alarm Module is designed to be a unitized, plug-in accessory for the main colorimetric analyzer.

Installation requirements are about the same (for either the Model 2072 or Model 2080) as for a Monitor IV, except that only 3-amp service is needed. If the Model 2052 dual-stage filtration system is employed, internal fouling of the analyzer

should present no special problems; however, upstream fouling of analyzer feed lines probably would cause the same problems as described earlier for similar analyzers.

The basic cost of the Model 2072 orthophosphorus analyzer is $3,750. It can be furnished to cover either of two standard ranges: 0 to 10 mg phosphorus per liter or 0 to 20 mg phosphorus per liter. Other ranges are available on request. Quoted limits for accuracy and stability are, respectively, ± 5 percent full scale and ± 5 percent full scale/day maximum calibration drift. Quoted limit of detection is 0.05 mg phosphorus per liter. Response time to reach 90 percent of true reading is 8 min. Reagent consumption is only 1.3 liters per week per reagent, and reagent stability is quoted as being 1 month at 25°C. On the other hand, the analyzer comes equipped with four 1-gallon reagent reservoirs, so the maintenance time for reagent replenishment is relatively low (once every 20 days). Also furnished is a 1-liter reservoir for standard orthophosphorus calibration solutions. Calibration is accomplished by manual stream switching, and it should be carried out daily for maximum accuracy. This standard calibration solution also should be completely changed each week.

The basic cost of the Model 2080 is $4,850. It also can be furnished for either of two ranges: 0 to 10 mg phosphorus per liter, or 0 to 20 mg phosphorus per liter, with other ranges available. Quoted accuracy, stability, limit of detection, and reagent stability are the same as for the Model 2072. Quoted response time to reach 90 percent of true reading is 95 min; however, adoption of Kamphake's new method[2] should lower this to 10 to 15 min. Reagent consumption is 2.5 liters per week per reagent; Enviro Control claims that reagent replenishment is required only once each 20 days. Calibration is accomplished by manual stream switching, and calibration requirements are the same as for the Model 2072.

As standard "equipment", each analyzer furnishes signal outputs in both current and voltage units (one of each). Options available are

current: 0 to 1 ma, 1 to 5 ma, 4 to 20 ma, 10 to 50 ma

voltage: 0 to 10 mv, 0 to 100 mv, 0 to 1 V, 0 to 5 V

Ionics' Model 1836 Automatic Phosphate Analyzer (APA) for Orthophosphorus

This automatic on-line colorimetric analyzer differs significantly from most of the other instrumentation described above. It is basically an improved version of the on-line

orthophosphorus analyzer that Dow field-tested successfully for 2 years in phosphate-removal installations at municipal sewage treatment plants in Cleveland, Ohio, and Grand Rapids, Mich. The Dow-Ionics APA is a much larger and heavier, steel-encased, hardware system than most other phosphorus analyzers. The APA measures 26 x 30 x 66 in. (66 x 76 x 167 cm), weighs 350 lb (159 kg), is designed to be floor-mounted on its own platform base, and is equipped with large-bore, motor driven valves and ¼ in. sample lines to minimize plugging by biological growths. As an added precaution, there is a periodic acid flush of the system (each 12 to 24 hr) to destroy any accumulated biological growths and to flush out deposited solids.

Even though the APA's photometric system employs only one optical cell, analyzer operation is sequenced in such a way that this single-cell photometer automatically compensates for turbidity and color in each new sample, as well as for moderate deposits on the cell's optical window. In effect, this automatically zeroes the analyzer before each new analysis. With relatively clean sample streams (e.g., final effluents), the APA will now operate relatively unattended for about 2 weeks; eventually, Ionics hopes to achieve this for raw sewage too through further developmental work.

A sample prefiltration system is not included as standard equipment with the APA because the filtration system required depends on the process stream being analyzed. For orthophosphorus measurements of primary effluent, biological reactor effluent, and final clarifier effluent, Ionics claims that only a Cuno Auto-Klean Type MSM filter is needed. The installed cost of such a filter, plus a sample pump, piping, etc., should not exceed $1,000. Prefiltration of raw sewage, whether before or after preliminary treatment, requires a much more expensive filtration system consisting of a Cuno-Flo, LN04 strainer (about $3,000), a Cuno Auto-Klean, Type MSM filter (about $500), a sample pump (about $200), and piping, valves, etc. The total installed cost for this latter system should not exceed $4,500, and Ionics hopes eventually to lower this to about $4,000 by placing large orders for strainers and filters with Cuno.

The following detailed information on the APA was furnished in a letter from Ionics:

1. The instrument will be supplied with a built-in stripchart recorder, standard outputs of 0 to 5 V dc to drive recorders and control devices, and a periodically updated "memory hold" output of 4 to 20 ma for computer interfacing. Optional current outputs of 1 to 5 ma and 10 to 50 ma will also be available.

2. Total analysis time per 50-ml sample will be about 10 to 12 min, with a "memory hold" of each successive orthophosphorus reading.

3. Analytical range will be adjustable to furnish full-scale orthophosphorus readings from 0 to 5 ppm up to 0 to 20 ppm. Quoted repeatability is ± 3 percent of range.

4. Power requirements will be 108-125 V ac, 4 amps, 60 Hz.

5. Environmentally controlled protective housing, drain lines, etc., will be required as for the preceding on-line colorimetric analyzers. A tapwater line, for analyzer flushing, will also be needed.

6. The following computer interfacing will be furnished as standard equipment:

   a. Phosphorus: 4 to 20 ma from memory: signal will be updated at the end of each analytical cycle.

   b. Event: Contact closure during acid-wash cycle.

   c. Event: Contact closure when any reagent supply is too low.

   d. Event: Contact closure when sample flow stops.

   e. Event: Contact closure when power supply fails or when power is shut off for instrument maintenance.

7. Approximate cost of the APA, without sample prefilters, should be about $9,500 to $10,000. This does not include installation costs which, according to Ionics, will probably be at least $1,000-$1,500.

8. Ionics is prepared to recommend and supply a total package for either monitoring or automatically controlling phosphorus levels in wastewater, using their Model 1836 APA plus auxiliary hardware. In fact, for those applications that can tolerate orthophosphorus measurements only once every 24 to 60 min, Ionics can furnish a system that uses one APA to manage as many as 5 different process streams,

so long as none of these multiple streams requires a change in the APA's orthophosphorus range setting. This analyzer sharing can be accomplished by the use of

a. Separate sample-filtration systems for each of the 2 to 5 process streams being analyzed, plus

b. an Automatic Stream Selector manifold, which costs about $3,000 (this price includes electronics and installation charges). The stream selector sequentially switches the main analyzer feedline from one source of sample to the next, following a preset sequencing pattern.

CONTROLLED-ENVIRONMENT PROTECTIVE HOUSING FOR AUTOMATIC ON-LINE COLORIMETRIC ANALYZERS

The functional requirements for this type of protective housing are virtually the same for any of the above analyzers. Since these requirements have already been described in the preceding section, the following information (supplied from an arbitrarily selected source for such housing) illustrates the costs of independently housing environmentally sensitive analyzers "out in the plant."

Controlled-environment housing, suitable for locating any of the subject analyzers directly adjacent to environmentally exposed unit processes, is available (in unassembled form) for $2,239 from the Winston Manufacturing Corporation.[3]

The quoted cost of the Winston structure does not include charges for field assembly, electric utility lines, drain lines, or piping for tap water (if needed). Winston refuses to furnish cost estimates for any of these items because such costs can vary widely. Instead, Winston recommends that each of their structures either be installed by skilled in-plant personnel or else be installed by a small, but reputable, local building, piping, or heating contractor. Examples of such contractors in the Greater Cincinnati area are shown in the following list furnished by Winston's Cincinnati representative, M & I Associates, Inc.:

1. Aggessive Piping Corporation
2. The Fred B. DeBra Company
3. E. J. Nolan Company
4. A. R. Nagel Company
5. Peck, Hannaford & Briggs Company

Winston's cost of $2,239 does not include options such as a separate concrete foundation (if needed), interior and exterior lighting fixtures, and insulation of water and drain lines with the possible requirements of steam or electric tracing for such lines to prevent freeze-up in extremely cold weather. Also excluded are estimates for the following costs, which also can vary widely for different locations, both geographic and inplant: tie-in of utility and drain lines to electric, water, and sewer mains, and yearly power requirements for lighting, heating, and cooling the structure.

ESTIMATED ANNUAL COSTS FOR PURCHASING, INSTALLING, OPERATING, AND MAINTAINING AN AUTOMATIC ON-LINE COLORIMETRIC ANALYZER

A rough cost estimate for installing and operating a wet chemical analyzer for making a single measurement at intervals of 5 min has been calculated and is shown in Table 3. The arbitrary assumptions made in making the cost estimate are listed below:

The parameter to be measured is ammonia.

The corresponding on-line analyzer (including all required accessories for the most stringent applications) is that furnished by Delta Scientific Corporation.

An on-site location requiring a controlled-environment protective enclosure is assumed, and the source of this enclosure is the Winston Manufacturing Corporation.

Selection of Delta Scientific equipment for these calculations is due to several factors. First, of all the analyzer systems described above, only those supplied by Technicon and Delta are presently capable of measuring all the subject parameters. Second, the installed price of approximately $5,500 for the complete Delta system (excluding independent protective housing) is significantly lower than Technicon's price of $8,288 (See Table 2) for an on-line colorimetric system that does not even embody an automatic sample-dilution module (Delta's price of $5,500 includes their patented Ratio Dilutor).

According to Delta Scientific Corporation, a conservative estimate for the "usable lifetime" of most automatic on-line colorimetric analyzers is about 5 years for process-control applications (the more expensive and rugged Ionics "APA" may possibly exceed this 5-year limitation). Beyond that point, component malfunctioning from constant, long-term operation begins to occur with increasing frequency. This steady increase in analyzer malfunctioning could be eliminated by a complete

Table 3

Cost Summary for Delta Scientific's On-Line Analyzer

Capital cost:	
Series 8000 analyzer/controller, installed	$5,500
Protective housing ($2,240 + 30% for erection)	2,910
Concrete slab and electric service	500
Total	$8,910
Operating and maintenance cost per year:	
Pump tubing replacement	60
Lamp replacement	5
Filter element replacement	500
Reagents	1,369
Electric power (instrument power, heating, and air conditioning of instrument housing)	160
Maintenance labor (208 man-hours/yr @ $5.20/hr)	1,082
Subtotal	$3,176
Debt service ($8,910 @ 6% for 5 yr)	2,115
Total cost per year	$5,291
Total cost for one analyzer installed at a 1 mgd plant	1.45¢/1,000 gal.

factory overhaul. However, such an overhaul is expensive; it completely removes the instrument from a possibly critical, process-control location for an indefinite period of time; and factory overhaul, after 5 years from date of original manufacture, will not usually produce an instrument possessing most of the state-of-the-art advances that could be obtained by the purchase of a new analyzer. For some applications, technical obsolescence alone might justify replacement of even a non-malfunctioning analyzer by a new instrument should the latter produce faster, more precise and/or more accurate measurements at greatly reduced maintenance costs. Thus, a five-year usable lifetime is a reasonably conservative estimate if the application is process control.

Delta guarantees their pump-tubing life to meet or exceed 2 years; therefore, the 5-year total for replacement tubing should not exceed $300, or $60 per year. Lamp replacement for the analyzer's photometer should be carried out every 24 months at a cost of $9.00 per lamp; therefore, replacement lamps over a 5-year period should total about $22.50, or $4.50 per year. Replacement of filter elements may be required as frequently as 10 times per year, for a yearly cost of $500. This estimate is based on filtration of raw sewage; if the process stream were a high quality secondary effluent, yearly costs for filter elements should not exceed $100-$150.

Reagent costs are significant for an analyzer that furnishes measurements continuously, 24 hours a day. All but the largest plants with well-equipped and adequately staffed laboratories probably would find it more economical to purchase stabilized reagent solutions (or dilutable reagent concentrates) in case lots from an outside supplier. Solutions of primary standards, however, might not be used in sufficient quantity to justify this for a process-control analyzer; however, such solutions are available as stable dilutable concentrates for very reasonable costs. Delta's charges for ammonia-analyzer reagents in case lots are shown in Table 4, accompanied by the estimated costs per year of using these pre-prepared reagents.

Table 4

Annual Cost of Using Delta Scientific's Pre-prepared Reagents

	Reagent	Quantity/Case	Price/Case	Volume Used/yr	Cost/yr
1)	Alkaline Phenol	4 x 1 gal.	$34.64	100 gal.	$866
2)	Alkaline Hypochlorite	4 x 1 gal.	$19.30	100 gal.	$483
3)	Standard NH_3 Solution (i.e., concentrate)	1-pint lots	$10/pint	2 pints	$ 20
	Annual total	---	---	---	$1,369

The prices in Table 4 are based on contract sales of reagents, whereby the customer must order a minimum of 12 cases (of either alkaline phenol or hypochlorite) in order for the prices shown to be valid. Delta also furnishes similar pre-prepared and stabilized reagents for their other colorimetric on-line analyzers for the subject process parameters. On the other hand, some customers prefer to make up their own reagents to save shipping costs to distant locations. Units are now being designed that will use only one-tenth the reagent volumes of the present models. However, in all other key aspects (i.e., accuracy, response time, cost, ease of maintenance, etc.), the new units will be like their present counterparts.

An important but intangible benefit of using pre-prepared stabilized solutions from a reputable commercial source is reliability. For process-control situations, the consequences of using reagents hastily prepared on-site by poorly trained or overworked plant personnel can cause any combination of (1) unnecessary analyzer downtime, (2) serious process upset, (3) failure to meet rigid discharge standards, or for some parameters, (4) excessive usage of costly process chemicals (e.g., alum for phosphate removal). Each plant superintendent or chief engineer must decide for himself if the slight savings (if any) of on-site reagent preparation and standardization is worth these risks. For comparison purposes, EPA Pilot Plant experience has found

that one-half man-day per week of chemist or laboratory technician time is required for preparing reagents and standard solutions to measure ammonia with an AutoAnalyzer. Assuming an hourly wage rate* of $5.20, this represents $1,082 per year. The cost of the chemicals themselves would add about $370 for a total of $1,452 per year. Since the AutoAnalyzer employs the same alkaline phenol-hypochlorite procedure as does the Delta analyzer, and since both analyzers consume about the same amounts of reagents, costs for on-site reagent preparation and standardization for Technicon's Monitor IV should approximate similar costs for the Delta analyzer.

Routine analyzer maintenance typically will average one-half man-day per week; naturally, this figure is based on the assumption that the unit is serviced according to the recommended schedule described in the analyzer's instruction manual. A factor that significantly affects maintenance time is the suspended solids concentration of the analyzer's feed stream. This, in turn, determines how frequently the dual-stage filtration unit must be serviced. The estimated one-half man-day per week is therefore only an average value, but it has been weighted toward high incoming suspended solids concentrations.

*All labor costs in this report are based on updated estimates furnished in "A New Concept for Operator Wages," JWPCF, 45 (2), 203-209 (Feb., 1973).

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2. Kamphake, L., (in preparation).

3. Instrument buildings may be obtained from the Winston Manufacturing Corp., Houston, Texas. Phone: 713-667-3351.

4. Personal communication from Mr. Robert Mankes, Delta Scientific Corp.

5. Personal communication from Mr. E. G. Trawick, Sr., Enviro Control.